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Wang, Yuanye

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WiMAX Evolution

WiMAX Evolution

Emerging Technologies and Applications

Marcos D. Katz

VTT, Finland

Frank H.P. Fitzek

Aalborg University, Denmark



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List of Contributors

Sassan Ahmadi

Intel Corporation
Mail Stop: JF3-336
2111 NE 25th Avenue
Hillsboro
OR 97124
USA
sassan.ahmadi@intel.com

Alexander Bachmutsky

Nokia Siemens Networks
313 Fairchild Drive
Mountain View
CA 94043
USA
alexander.bachmutsky@nsn.com

Thomas Michael Bohnert

SAP Research CEC Zurich
Kreuzstrasse 20
8008 Zurich
Switzerland
thomas.michael.bohnert@sap.com
and tmb@nginet.de

Sandrine Boumard

VTT Technical Research Centre of Finland
Kaitoväylä 1
FI-90571 Oulu
Finland
sandrine.boumard@vtt.fi

Aaron Byman

EB Corp.
Tutkijantie 7
90570 Oulu
Finland
Aaron.Byman@elektrobit.com

Paola Cardamone

THALES Security Solutions and Services S.p.A.
via Provinciale Lucchese, 33
50019 Sesto Fiorentino
Firenze
Italy
paola.cardamone@gmail.com

Thomas Casey

Elektrobit
Keilasatama 5
02150 Espoo
Finland
thomas.casey@elektrobit.com

Chan-Byoung Chae

Wireless Networking and Communications
Group
Department of Electrical and Computer
Engineering
The University of Texas at Austin
Austin, TX
USA
cbchae@ece.utexas.edu

Francesco Chiti

Department of Electronics and
Telecommunications
University of Florence
via di S. Marta 3
I-50139 Florence
Italy
francesco.chiti@unifi.it

Juan Luis Corral

Nanophotonics Technology Center
Universidad Politécnica de Valencia
Camino de Vera s/n
46022 Valencia
Spain
jllcorral@ntc.upv.es

Marília Curado

DEI-CISUC
University of Coimbra
Polo II, Pinhal de Marrocos
3030-290 Coimbra
Portugal
marilia@dei.uc.pt

Suvra Sekhar Das Ph.D

Tata Consultancy Services
Innovation Lab, Convergence Practice,
Tata Consultancy Services
Kolkata
India
suvra.das@tcs.com

Michael Devetsikiotis

Electrical and Computer Engineering
North Carolina State University
Raleigh
NC 27695-7911
USA
mdevets@ncsu.edu

Romano Fantacci

Department of Electronics and
Telecommunications
University of Florence
via di S. Marta 3
I-50139 Florence
Italy
romano.fantacci@unifi.it

Frank H.P. Fitzek

Electronic Systems – Mobile Device Group
Aalborg University
Denmark
ff@es.aau.dk

Francisco Fontes

Portugal Telecom Inovação
R. Eng. José Ferreira Pinto Basto
3810-106 Aveiro
Portugal
fontes@ptinovacao.pt

Avraham Freedman

Hexagon System Engineering Ltd
P.O. Box 10149
14 Imber Street
Suite 51
Petach Tikva 49001
Israel
avif@hexagonltd.com

Ilkka Harjula

VTT Technical Research Centre of Finland
Kaitoväylä 1
FI-90571 Oulu
Finland
ilkka.harjula@vtt.fi

Matthias Hollick

Multimedia Communications Lab (KOM)
TU Darmstadt
Merckstr. 25
64283 Darmstadt
Germany
matthias.hollick@kom.tu-darmstadt.de

Kaibin Huang

Department of Electrical and Electronic
Engineering
Hong Kong University of Science and
Technology
Hong Kong
huangkb@ieee.org

Jie Hui

Intel Communication Technology Lab
Portland, Oregon
USA
Jie.Hui@intel.com

Jyrki Huusko

VTT Technical Research Centre of Finland
Kaitoväylä 1
FI-90571 Oulu
Finland
Jyrki.Huusko@vtt.fi

Takao Inoue

Wireless Networking and Communications
Group
Department of Electrical and Computer
Engineering
The University of Texas at Austin
Austin, TX
USA
inoue@ece.utexas.edu

Riku Jäntti

Department of Communications and Networking
Helsinki University of Technology
PL 3000
02015 TKK Espoo
Finland
riku.jantti@tkk.fi

Marcos D. Katz

VTT Technical Research Centre of Finland
Kaitoväylä 1
FI-90571 Oulu
Finland
Marcos.Katz@vtt.fi

Giada Landi

Nextworks
Via Turati, 43
56125 Pisa
Italy
g.landi@nextworks.it

Mika Lasanen

VTT Technical Research Centre of Finland
Kaitoväylä 1
FI-90571 Oulu
Finland
mika.lasanen@vtt.fi

Moshe Levin

Hexagon System Engineering Ltd
P.O. Box 10149
14 Imber Street, Suite 51
Petach Tikva 49001
Israel
moshe@hexagonltd.com

Roberto Llorente

Nanophotonics Technology Center
Universidad Politécnica de Valencia
Camino de Vera s/n
46022 Valencia
Spain
jllcorral@ntc.upv.es

Leonardo Maccari

Department of Electronics and
Telecommunications
University of Florence
via di S. Marta 3
I-50139 Florence
Italy
leonardo.maccari@unifi.it

Dania Marabissi

Department of Electronics and
Telecommunications
University of Florence
via di S. Marta 3
I-50139 Florence
Italy
dania.marabissi@unifi.it

Javier Martí

Nanophotonics Technology Center
Universidad Politécnica de Valencia
Camino de Vera s/n
46022 Valencia
Spain
jmarti@ntc.upv.es

Ricardo Matos

IT/UA Telecommunications Institute/University
of Aveiro
Campus Universitário de Santiago
3810-193 Aveiro
Portugal
ricardo.matos@ua.pt

Parag S. Mogre

Multimedia Communications Lab (KOM)
TU Darmstadt
Merckstr. 25
64283 Darmstadt
Germany
parag.mogre@kom.tu-darmstadt.de

Edmundo Monteiro

University of Coimbra
Pinhal de Marrocos, Polo II
3030 Coimbra
Portugal
edmundo@dei.uc.pt

Pedro Neves

Portugal Telecom Inovação
R. Eng. José Ferreira Pinto Basto
3810-106 Aveiro
Portugal
pedro-m-neves@ptinovacao.pt

Jari Nurmi

Elektrobit
Kehräämöntie 5
87400 Kajaani
Finland
jari.nurmi@elektrobit.com

Ioannis Papapanagiotou

Electrical and Computer Engineering
North Carolina State University
Raleigh
NC 27695-7911
USA
ipapapa@ncsu.edu

Kostas Pentikousis

VTT Technical Research Centre of Finland
 Kaitoväylä 1
 FI-90571 Oulu
 Finland
 kostas.pentikousis@vtt.fi

Jarno Pinola

VTT Technical Research Centre of Finland
 Kaitoväylä 1
 FI-90571 Oulu
 Finland
 jarno.pinola@vtt.fi

Esa Piri

VTT Technical Research Centre of Finland
 Kaitoväylä 1
 FI-90571 Oulu
 Finland
 esa.piri@vtt.fi

Valentín Polo

AIMPLAS
 València Parc Tecnològic
 C/ Gustave Eiffel, 4
 46980 Paterna
 Spain
 vpolo@aimplas.es

Jonás Porcar

DAS Photonics S.L.
 Camino de Vera s/n
 Building 8F
 46022 Valencia
 Spain
 jporcar@dasphotonics.com

Doug Pulley

picoChip
 Riverside Buildings
 108 Walcot Street
 Bath BA1 5BG
 UK
 doug.pulley@picochip.com

Muhammad Imadur Rahman Ph.D

Center for TeleInfrastruktur (CTIF)
 Department of Electronic Systems
 Aalborg University
 Denmark
 imr@ieee.org

Antonio José Ramírez

DAS Photonics S.L.
 Camino de Vera s/n
 Building 8F
 46022 Valencia
 Spain
 aramirez@dasphotonics.com

Wonil Roh

Samsung Electronic Corp., Ltd
 416 Maetan-3dong
 Yeongtong-gu
 Suwon-city
 Gyeonggi-do, 443-742
 Korea
 wonil.roh@samsung.com

Susana Sargento

IT/UA Telecommunications Institute/University
 of Aveiro
 Campus Universitário de Santiago
 3810-193 Aveiro
 Portugal
 susana@ua.pt

Gerrit Schulte

acticom
 Am Borsigturm 42
 13507 Berlin
 Germany

Christian Schwingenschloegl

Siemens AG
 Corporate Technology, Information and
 Communication
 Otto-Hahn-Ring 6
 81730 Munich
 Germany
 chris.schwingenschloegl@siemens.com

Patrick Seeling

Department of Computing and
 New Media Technologies
 University of Wisconsin - Stevens Point
 Science Building, Room B243
 Stevens Point
 WI 54481
 USA
 pseeling@uwsp.edu

Paulo Simões

DEI-CISUC
University of Coimbra
Polo II, Pinhal de Marrocos
3030-290, Coimbra
Portugal
psimoes@dei.uc.pt

Chris Smart

picoChip
Riverside Buildings
108 Walcot Street
Bath BA1 5BG
UK
chris.smart@picochip.com

Clare Somerville

picoChip
Riverside Buildings
108 Walcot Street
Bath BA1 5BG
UK
clare.somerville@picochip.com

Roshni Srinivasan

Intel Corporation
2200 Mission College Boulevard RNB 5-123
Santa Clara
CA 95052
USA
roshni.srinivasan@intel.com

Dirk Staehle

University of Wuerzburg
Institute of Computer Science
Chair of Distributed Systems
Am Hubland
D-97074 Wuerzburg
Germany
dstaehle@informatik.uni-wuerzburg.de

Ralf Steinmetz

Multimedia Communications Lab (KOM)
TU Darmstadt
Merckstr. 25
64283 Darmstadt
Germany
ralf.steinmetz@kom.tu-darmstadt.de

Daniele Tarchi

Department of Electronics and
Telecommunications
University of Florence
via di S. Marta 3
I-50139 Florence
Italy
daniele.tarchi@unifi.it

Rath Vannithamby

Intel Corporation
2111 NE 25th Avenue
Mail Stop JF3-206
Hillsboro
OR 97124
USA
rath.vannithamby@intel.com

Borja Vidal

Nanophotonics Technology Center
Universidad Politécnica de Valencia
Camino de Vera s/n
46022 Valencia
Spain
borvirod@ntc.upv.es

Nenad Veselinovic

Elektrobit
Keilasatama 5
02150 Espoo
Finland
nenad.veselinovic@elektrobit.com

Yuanye Wang M.Sc

Aalborg University
Radio Access Technology Section
Department of Electronic Systems
Aalborg University
Denmark
ywa@es.aau.dk

Matti Weissenfelt

VTT Technical Research Centre of Finland
Kaitoväylä 1
FI-90571 Oulu
Finland
matti.weissenfelt@vtt.fi

Vladimir Yanover

Alvarion Ltd
11/4 Nahshon Str.
Kfar Saba 44447
Israel
vladimir.yanover@alvarion.com

Qi Zhang

Department of Communications,
Optics and Materials
Technical University of Denmark
Denmark
qz@com.dtu.dk

Xiongwen Zhao

Elektrobit
Keilasatama 5
02150 Espoo
Finland
xiongwen.zhao@elektrobit.com

Andreas Ziller

Siemens AG
Corporate Technology, Information and
Communication
Otto-Hahn-Ring 6
81730 Munich
Germany
andreas.ziller@siemens.com

David Zorrilla

DAS Photonics S.L.
Camino de Vera s/n
Building 8F
46022 Valencia
Spain
dzorrilla@dasphotonics.com

Foreword

Mobile WiMAX: the Enabler for the Mobile Internet Revolution

The Internet has become one of the most important assets for the growth of economies across the globe. More than a billion people use the Internet at their workplace and in their daily lives for business interactions, social interactions and entertainment. The Internet has had a profound effect on the economy of developed and developing nations having made economic activity more efficient, accessible and affordable. Most of the productivity gains in today's economies are thanks to the Internet and e-commerce. There have been profound social impacts from increased access to valuable information and social interaction between the masses. The impact is at many socioeconomic levels: business productivity, energy savings, healthcare delivery, improved government functions, education, improved citizen interactions (locally and globally), etc. Despite the benefits of the Internet, today only about 20% of the World's population have access to the Internet. In particular, the emerging countries that could benefit greatly are seriously deprived of this valuable asset. There are a number of reasons for the small number of users in the emerging countries: lack of infrastructure, affordability of personal computers, unaffordable access fees, etc.

The next big step in the evolution of the Internet is ubiquitous availability enabled through mobile Internet. This revolutionary step is poised to increase the value of the Internet enormously as it will create a fundamental shift in the use of the Internet by bringing the Internet to the users as opposed to users having to go to the Internet. For this vision to become a reality, a number of requirements need to be met. First and foremost, affordable and ubiquitous mobile Internet access needs to be provided using the mobile cellular concept. This is poised to be fulfilled thanks to mobile WiMAX. Secondly, affordable and low-power mobile Internet devices and mobile PCs are needed. This is also happening with the computer industry making huge strides in making these devices more affordable. The low-cost netbook category with examples such as the ASUS Eee PC and variety of small mobile PCs or Mobile Internet Devices (MIDs) are now available and will undoubtedly become even more affordable in the near future.

Mobile WiMAX has been designed with the purpose of enabling mobile Internet from the physical layer to the network layer. The physical layer design relies on Orthogonal Frequency Division Multiple Access (OFDMA) and Multiple Input Multiple Output (MIMO) as the two key technologies to optimize coverage and spectral efficiency. In addition, sophisticated techniques for link adaptation and error control provide improved performance and robustness. Mobile WiMAX technology includes many other important aspects such as security

and power-saving methods, provisions for location-based services, support for hierarchical deployments, quality-of-service, and open Internet user and network management schemes, which are essential in enabling deployment and consumer adoption of the technology.

The Internet is dynamic by nature and is evolving rapidly on the application level and creating ever-increasing demands on connectivity. Studies indicate that Internet traffic has been doubling roughly every two years. Mobile Internet will undoubtedly change the Internet as we know it today and may create even more traffic than ever anticipated. Mobile WiMAX needs to evolve constantly to keep up with the growth of mobile Internet. The WiMAX industry has already been working on the next technology in IEEE 802.16m to build the basis for the next generation of mobile Internet.

This book provides the material that is essential to understand the underlying concepts for mobile WiMAX and it also provides an overview of technologies that will enable the evolution of the technology in the future. I sincerely hope that the book will further motivate researchers and developers to create innovative ideas and techniques that will help fulfill the promise of the new era of mobile Internet.

Siavash M. Alamouti, Intel Fellow
Chief Technology Officer, Mobile Wireless Group

Preface

The remarkable development of wireless and mobile communications in the last two decades is a unique phenomenon in the history of technology. Even the most optimistic predictions on penetration of mobile subscribers and capabilities of wireless devices have been surpassed by reality. In a quarter of century the number of mobile subscribers soared from a few to half the world population (in 2008), and according to some forecasts by 2010 the number of mobile users will exceed the number of toothbrush users (four billion). The Wireless World Research Forum (WWRF) envisions that by year 2017 there will be seven trillion wireless devices serving seven billion people. Two main development directions in untethered communications can be identified, wide-area communications, with the omnipresent cellular systems as the most representative example, and short-range communications, involving an array of networking technologies for providing wireless connectivity over short distances, for instance Wireless Local Area Networks (WLANs), Wireless Personal Area Networks (WPANs), Wireless Body Area Networks (WBANs), Wireless Sensor Networks (WSNs), Bluetooth, etc. Recent years have witnessed an enormous growth in interest in the metropolitan wireless networks. This should not be a surprise, as in 2008, for the first time in history more than half of the world population lives in urban areas, according to the United Nations Population Fund. WiMAX (Worldwide Interoperability for Microwave Access) is the most representative worldwide initiative focusing on metropolitan communications. WiMAX, based on the IEEE 802.16 standard, defines wireless networks combining key characteristics of wide-area cellular networks as well as short-range networks, namely mobility and high data throughput. IEEE 802.16 is a very active and rapidly evolving standard that serves as the fundamental basis for WiMAX systems. Several amendments are currently being developed addressing particular technical aspects or capabilities, including 802.16g, 802.16h, 802.16i, 802.16j, 802.16k and 802.16m. There are already several books dealing with WiMAX technology, describing mostly the basic operating principles, current standards and associated technical solutions. The current vertiginous developments in the WiMAX arena have lead the Editors to conceive of this book, taking over where most of the published WiMAX volumes left off, that is, looking in future directions. Leading research scientists and engineers from key WiMAX industry, academia and research centers worldwide have contributed to this book with their ideas, concepts, concrete technical suggestions and visions.

As WiMAX as a whole encompasses a very broad area, it is impossible to find a single author able to write in detail about a large array of advanced concepts and solutions applicable at different system levels of WiMAX: the Editors have thus invited specialists in the field to contribute with their ideas in different chapters. The goal of this book is

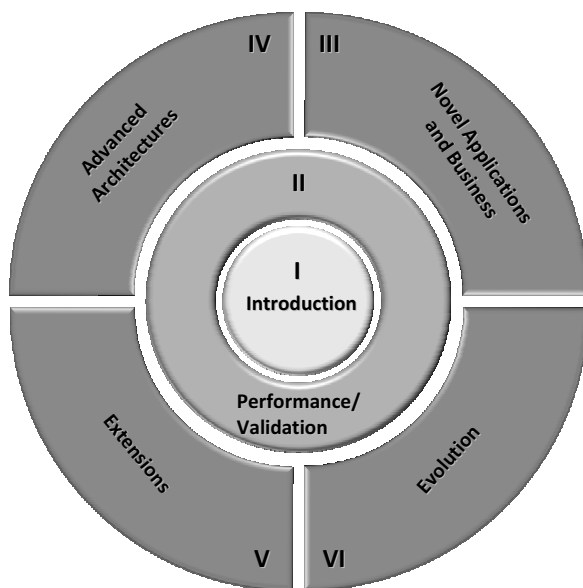


Figure 1 WiMAX evolution: organization of the book.

to create concrete supportive links between the presented concepts and future metropolitan communication systems, discussing technical solutions as well as novel identified scenarios, business applications and visions that are likely to become integral parts of the future WiMAX. Thus, this book tries to answer questions including the following. Which are the emerging WiMAX technologies that are being developed? What are the new scenarios for deploying WiMAX? What are the most promising WiMAX applications and business? How are standards evolving? What are the visions of industry? What are the capabilities and measured performance of real (commercial) WiMAX systems?

As shown in Figure 1, this book has been organized into six independent parts, covering different aspects of WiMAX technology and its evolution. Part One overview of the current state of WiMAX technology, serving as an introduction to WiMAX. Part Two presents measurements and validation results carried out on real state-of-the-art WiMAX testbeds (fixed and mobile), providing unique results on the achievable capabilities of commercial equipment operating in real scenarios. Novel scenarios and business cases for WiMAX are considered in Part Three. In Part Four new promising architectures for WiMAX are discussed, including wireless sensor networks, mesh and cooperative networking as well as femtocells. Part Five discusses several extensions to the current WiMAX, that is, new solutions that can be used in conjunction with the current WiMAX standard. Finally, Part Six looks into technical developments beyond the immediate WiMAX future, including PHY and MAC evolution, prospects and visions, emerging technologies, evolution of standards, etc.

WiMAX Evolution: Emerging Technologies and Applications is a book intended for research, development and standardization engineers working in industry, as well as for scientists in academic and research institutes. Graduate students conducting research in

WiMAX and next generation mobile communications will also find in this book relevant material for further research. The Editors think that this book provides novel views and detailed technical solutions, foreseeing future WiMAX while being a stimulating source of inspiration for further advanced research in the field.

The Editors welcome any suggestions, comments or constructive criticism on this book. Such feedback will be used to improve forthcoming editions. The Editors can be contacted at wimaxeditor@es.aau.dk.

Marcos D. Katz
VTT (Technical Research Centre of Finland), Finland

Frank H.P. Fitzek
Aalborg University, Denmark

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List of Acronyms

μC MicroController	ASN Access Service Network
16-QAM 16 Quadrature Amplitude Modulation	ASN-GW Access Service Network Gateway
2G 2nd Generation	ATM Asynchronous Transfer Mode
3G 3rd Generation	AVC Advanced Video Coding
3GPP 3rd Generation Partnership Project	AWGN Additive White Gaussian Noise
3GPP2 3rd Generation Partnership Project 2	BD Block Diagonalization
4G Fourth Generation	BE Best Effort
A/V Audio/Visual	BER Bit Error Rate
AAA Authentication, Authorization and Accounting	BF Beamforming
AAS Adaptive Antenna System	BGP Border Gateway Protocol (routing)
AC Admission Control; Antenna Circulation	BLER Block Error Rate
ACIR Adjacent Channel Interference Ratio	BOM Bill Off Materials
ACK Acknowledgement	bps Bits Per Second
ACR Absolute Category Rating	BPSK Binary Phase Shift Keying
ADSL Asymmetric Digital Subscriber Line	BS Base Station
AG Antenna Grouping	BSID Base Station Identifier
AMC adaptive modulation and coding	BWA Broadband Wireless Access
AMR Adaptive Multi-Rate	C/I Carrier to Interference Ratio
AMS Adaptive MIMO Switching	CAPEX Capital Expenditures
AP Access Point	CATV Cable Television
APD Adaptive Power Distribution	CBC Cipher Block Chaining
APFR Adaptive Power Fixed Rate	CBF Coordinated Beamforming
API Application Programming Interface	CBR Constant Bit Rate
APMC Adaptive Power, Modulation and Coding	CC Chase Combining; Convolutional Code; Coordination Center
AQ Assessed QoS	CCF Call Control Function
ARP Address Resolution Protocol	CCP2P Cellular Controlled Peer to Peer
ARQ Automatic Repeat Request	CDF Cumulative Distribution Function
AS Antenna Selection	CDL Clustered Delay Line

CDMA Code Division Multiplex Access	DMTBR Dynamic Multiple-Threshold Bandwidth Reservation
CELP Code Excited Linear Prediction	DNS Domain Name System
CH Compressed Header	DNS-SD Dynamic Name System Service Discovery
C/I Carrier-to-Interference Ratio	DPT Dirty Paper Theory
CID Connection Identifier	DRR Deficit Round Robin
CI-STBC Coordinate Interleaved Space–Time Block Code	DRX Discontinuous Reception
CMIP Client Mobile IP	DS-CDMA Direct Sequence Code Division Multiple Access
CN Correspondent Node	DSL Digital Subscriber Line
CN Core Network	DSLAM Digital Subscriber Line Access Multiplexer
CNL VTT Converging Networks Laboratory	DWRR Deficit Weighed Round Robin
CNR Channel-to-Noise Ratio	EAP Extensible Authentication Protocol
CoA Care-of-Address	ECMP Equal Cost Multi-Path
CODEC Compression/Decompression	EDF Earliest Deadline First
COST European Cooperation in the Field of Scientific and Technical Research	EpBR Energy per Bit Ratio
COTS Commercial Off The Shelf	ertPS Extended Real-Time Polling Service
CP Cyclic Prefix	ERT-VR Extended Real-Time Variable Rate
CPE Customer Premises Equipment	ESP Encapsulating Security Payload
CPS Common Part Sublayer	ETX Expected Transmission Count
CPU Central Processing Unit	EVD Eigenvalue Decomposition
CQI Channel Quality Indicator	EVRC Enhanced Variable Rate Codec
CQICH Channel Quality Indicator Channel	FA Foreign Agent
CRC Cyclic Redundancy Check	FBSS Fast Base Station Switching
CS Convergence Sublayer	FCH Frame Control Header
C-SAP Control Service Access Point	FDD Frequency-Division Duplex
CSG Closed Subscriber Group	FDM Frequency Division Multiplexing
CSI Channel State Information	FEC Forward Error Correction
CSN Connectivity Services Network	FER Frame Error Rate
CTS Clear to Send	FFMS Forest Fire Monitoring Station
DAS Distributed Antenna System	FFT Fast Fourier Transform
DCA Dynamic Channel Allocation	FIFO First In First Out
DCD Downlink Channel Descriptor	FP Framework Programme
DCF Discounted Cash Flow	FPAR Fixed Power Adaptive Rate
DES Data Encryption Standard	FPGA Field-programmable Gate Array
DFB Distributed Feedback	FTP File Transfer Protocol
DHCP Dynamic Host Configuration Protocol	FUSC Fully Used Subcarriers
DL Downlink	GA Generic Adapter

GIS Geographic Information Systems	IPv6 Internet Protocol version 6
GIST General Internet Signaling Transport	IQ Intrinsic QoS
GMH Generic MAC Header	IQA Instrumental Quality Assessment
GoS Grade of Service	IRR Internal Rate of Return
GPRS General Packet Radio Service	ISD Inter-site Distance
GPS Global Positioning System	IST Information Society Technologies
GRE Generic Routing Encapsulation	ITU International Telecommunications Union
GSM Global System for Mobile Communications	kbps kilobits per second (1000 bits s^{-1})
GTP GPRS Tunneling Protocol	KPI Key Performance Indicator
GUI Graphical User Interface	L1 Layer 1 (Physical Layer)
GW Gateway	L2 Layer 2 (Data Link Layer)
HA High Availability; Home Agent	L2TP Layer 2 Tunneling Protocol
HARQ Hybrid Automatic Repeat Request	LA Link Adaptation
HD High Definition	LACP Link Aggregation Control Protocol
HFC Hybrid Fiber Coaxial	LAG Ling Aggregation
HFDD Half-duplex Frequency Division Duplex	LAN Local Area Network
HFR Hybrid Fiber Radio	LBC Load Balancing Cycle
HHO Hard Handover	LBS Location Based Services
HO Handover	LDAP Lightweight Directory Access Protocol
HSDPA High Speed Data Packet Access	LLA Low Level Agent
HSPA High Speed Packet Access	LLL Lenstra–Lenstra–Lovász
HSRP Hot Standby Router Protocol	LOS Line-of-Sight
HTTP Hyper Text Transfer Protocol	LPC Linear Predictive Coding
HW Hardware	LPM Loss Packet Matrix
ICMP Internet Control Message Protocol	LSB Least Significant Bit
ICT Information and Communication Technologies	LTE Long Term Evolution
ID Identification	LU Lenstra–Lenstra–Lovász
IETF Internet Engineering Task Force	MAC Medium Access Control
IFFT Inverse Fast Fourier Transform	MAN Metropolitan Area Network
IMDD Intensity Modulation, Direct Detection	MAP Medium Access Protocol; Mobile Application Part
IMS IP Multimedia Subsystem	MBAC Measurement Based Admission Control
IMT International Mobile Telecommunications	MBB Make Before Break
IP Internet Protocol	MBMS Multimedia Broadcast Multicast Service
Ipssec Internet Protocol Security	Mbps Megabits per second ($1\,000\,000 \text{ bits s}^{-1}$)
IPTV Internet Protocol Television	MBS Mesh Base Station; Multicast and Broadcast Service
IPv4 Internet Protocol version 4	MCBCS Multicast and Broadcast Service
	MCS Modulation and Coding Scheme

MCW	Multi Codeword	NCMS	Network Control and Management System
MDHO	Macro Diversity Handover	NDCQ	Nondegenerate Constraint Qualification
MeSH	IEEE 802.16-2004 Mesh Mode	NE	Network Element
MIB	Management Information Base	NET	Network Layer
MICS	Media Independent Command Service	NGMN	Next-Generation Mobile Network
MIES	Media Independent Event Service	NGN	Next Generation Network
MIH	Media Independent Handover	NIHO	Network Initiated Handover
MIHF	Media Independent Handover Function	NLOS	Non-Line-of-Sight
MIHO	Mobile Initiated Handover	NMS	Network Management System
MIHU	Media Independent Handover User	NPV	Net Present Value
MIIS	Media Independent Information Service	NRM	Network Reference Model
MIMO	Multiple Input Multiple Output	nrt	Non-real-time
MIP	Mobile Internet Protocol	nrtPS	Non-real-time Polling Service
ML	Maximum Latency	NSIS	Next Steps in Signaling
MLD	Maximum Likelihood Decoder	NSLP	NSIS Signaling Layer Protocol
MLI	Modulation Level Information	NTLP	NSIS Transport Layer Protocol
MM	Mobility Management	NTP	Network Time Protocol
MMF	Multimode Fiber	NWG	Network Working Group
MMR	Mobile Multihop Relay	O&M	Operations and Management
MMSE	Minimum Mean Square Error	OFDM	Orthogonal Frequency Division Multiplexing
MN	Mobile Node	OFDMA	Orthogonal Frequency Division Multiple Access
MOS	Mean Opinion Score	OGBF	Orthogonal Beamforming
MPEG	Moving Picture Experts Group	OMC	Operation and Maintenance Center
MRC	Maximum Ratio Combining	OMF	Operation and Maintenance Function
MRT	Maximum Ratio Transmission	OPEX	Operational Expenditures
MRTR	Minimum Reserved Traffic Rate	OSPF	Open Shortest Path First
MS	Mobile Station	P2P	Peer to Peer
M-SAP	Management Service Access Point	PA	ITU Pedestrian A
MSB	Most Significant Bit	PB	ITU Pedestrian B
MSDU	MAC Service Data Unit	PAN	Personal Area Network
MSE	Mean Square Error	PAPR	Peak to Average Power Ratio
MSID	Mobile Subscriber ID	PBE	Perfect Bayesian Equilibrium
MSTR	Maximum Sustained Traffic Rate	PC	Paging Controller; Power Control
MTBF	Mean Time Between Failures	PCM	Pulse Code Modulation
MTU	Maximum Transmission Unit	PDA	Personal Digital Assistant
NACK	Negative Acknowledgement	PDU	Protocol Data Unit
NAI	Network Access Identifier		
NC	Network Coding		

PEP Performance Enhancing Proxy	rt real-time
PER Packet Error Rate	RTP Real-time Transport Protocol
PHB Per Hop Behavior	rtPS Real-Time Polling Service
PHY Physical Layer	RTS Request to Send
PLC Packet Loss Concealment	RTT Round Trip Time
PLR Packet Loss Rate	RT-VR Real-Time Variable Rate
PMIP Proxy Mobile IP	Rx Receive
PMP Point to Multipoint	SA Specific Adapter
PN Psedorondam Noise	SAF Service Availability Forum
POF Plastic Optical Fiber	SAMPDA Simple Adaptive Modulation and Power Adaptation Algorithm
PQ Perceived QoS	SAP Service Access Point
PSTN Public Switched Telephone Network	SBS Serving Base Station
PTMP Point-to-Multipoint	SC Serra do Carvalho
PTP Precision Time Protocol	SCM Spatial Channel Model
PTP Point-to-point	SCR Spare Capacity Report
PU2RC Per-User Unitary and Rate Control	SCTP Stream Control Transmission Protocol
PUSC Partially Used Subcarrier; Partially Used Subchannelization	SCW Single Codeword
QAM Quadrature Amplitude Modulation	SDMA Spatial Division Multiple Access
QoE Quality of Experience	SDU Service Data Unit
QoS Quality of Service	SE Spectral Efficiency
QPSK Quadrature Phase-Shift Keying	SF Service Flow
RADIUS Remote Authentication Dial-In User Service	SFDR Spurious Free Dynamic Range
RAN Radio Access Network	SFM Service Flow Management
RAU Remote Antenna Unit	SID Silent Insertion Descriptor
RB Resource Block	SINR Signal-to-Interference + Noise Ratio
RF Radiofrequency	SIP Session Initiation Protocol
RFC Request for Comments (IETF standard document)	SISO Single Input Single Output
RMF Resource Management Function	SL Serra da Lousã
RMS Root Mean Square	SLA Service Level Agreement
RoF Radio-over-Fiber	SM Spatial Multiplexing
ROHC Robust Header Compression	SMF Singlemode Fiber
RRM Radio Resource Management	SMS Short Message Service
RS Relay Station	SNMP Simple Network Management Protocol
RSS Received Signal Strength	SNR Signal-to-Noise Ratio
RSSI Received Signal Strength Indicator	S-OFDMA Scalable Orthogonal Frequency Division Multiple Access
	SOHO Small Office/Home Office
	SON Self-Organized Network

SP Synchronization Pattern	VBR Variable Bit Rate
SRA Simple Rate Adaptation	VCEG Video Coding Experts Group
SRD System Requirement Document	VCSEL Vertical Cavity Surface Emitting Laser
SS Subscriber Station	VDT Virtual Drive Test
SSL Secure Socket Layer	VLSI Very-Large-Scale Integration
STBC Space Time Block Coding	VoD Video on Demand
STC Space-Time Coding	VoIP Voice over Internet Protocol
SUI Stanford University Interim	VP Vector Perturbation
SW Software	VR Virtual Router
TBS Target Base Station	VRRP Virtual Router Redundancy Protocol
TCP Transmission Control Protocol	W3GPP third generation partnership project
TDD Time Division Duplex	WAC Wireless Access Controller
TDM Time Division Multiplexing	WDM Wavelength Division Multiplexing
TDMA Time Division Multiple Access	WEIRD WiMAX Extension to Isolated Research Data Networks
TEM Telecommunications Equipment Manufacturer	WEP Wired Equivalent Privacy
TETRA Terrestrial Trunked Radio	WiFi Wireless Fidelity
TTI Transmission Time Interval	WiMAX Worldwide Interoperability for Microwave Access
TTP Trusted Third Party	WINNER Wireless World Initiative New Radio
TWG Technical Working Group	WLAN Wireless Local Area Network
Tx Transmit	W-LSB Windowed Least Significant Bits
UC University of Coimbra	WMAN Wireless Metropolitan Area Network
UCD Uplink Channel Descriptor	WMN Wireless Mesh Network
UDP User Datagram Protocol	WNC Wireless Network Coding
UGS Unsolicited Grant Service	WNEA WiMAX Network Element Advertisement
UL Uplink	WPAN Wireless Personal Area Network
UMB Ultra Mobile Broadband	WRR Weighted Round Robin
UMTS Universal Mobile Telecommunications System	WSN Wireless Sensor Network
UMTS-LTE Universal Mobile Telecommunications Systems – Long Term Evolution	WT WiMAX Terminal
VAD Voice Activity Detection	WWRF Wireless World Research Forum
	ZFBF Zero-Forcing Beamforming